

TABLE 2.—Vapor pressures at pyrheliometric stations on days when solar radiation intensities were measured.

Washington, D. C.			Madison, Wis.			Lincoln, Nebr.		
Date.	8 a. m.	8 p. m.	Date.	8 a. m.	8 p. m.	Date.	8 a. m.	8 p. m.
1918.	mm.	mm.	1918.	mm.	mm.	1918.	mm.	mm.
Nov. 1.....	4.57	3.81	Nov. 8.....	8.48	6.50	Nov. 1.....	3.63	7.57
2.....	4.75	3.45	12.....	4.75	2.74	2.....	3.99	9.47
6.....	4.57	4.75	13.....	3.30	3.00	3.....	5.79	7.04
7.....	4.57	6.02	14.....	3.81	6.50	8.....	4.57	4.37
8.....	5.79	7.57	23.....	1.98	2.49	9.....	3.63	5.36
11.....	3.81	3.99	25.....	2.49	2.87	11.....	5.56	8.48
12.....	3.63	4.57	26.....	3.15	2.36	13.....	3.99	7.29
13.....	4.57	5.36	27.....	2.49	3.45	18.....	3.30	4.37
14.....	3.30	3.81	29.....	2.87	2.49	19.....	3.45	5.79
19.....	5.79	6.50				25.....	2.74	3.45
26.....	2.87	3.63				29.....	1.96	3.63
27.....	2.87	3.99				30.....	2.16	4.57
29.....	6.02	3.81						
30.....	3.30	2.49						

TABLE 3.—Daily totals and departures of solar and sky radiation during November, 1918.

[Gram-calories per square centimeter of horizontal surface.]

Day of month.	Daily totals.			Departures from normal.			Excess or deficiency since first of month.		
	Washing-ton.	Mad-ison.	Lin-coln.	Washing-ton.	Mad-ison.	Lin-coln.	Washing-ton.	Mad-ison.	Lin-coln.
Nov. 1.....	cal. 183	cal. 277	cal. 354	cal. -75	cal. 84	cal. 97	cal. -75	cal. 84	cal. 97
2.....	217	152	232	-39	-39	78	-114	45	175
3.....	308	51	338	54	-137	87	-60	-92	262
4.....	217	196	235	-35	10	-13	-95	-82	249
5.....	203	214	47	-47	30	-198	-142	-52	51
6.....	304	208	78	57	27	-165	-85	-25	-114
7.....	290	60	44	47	-119	-196	-38	-144	-310
8.....	242	180	306	2	-16	69	-38	-160	-241
9.....	72	57	353	-164	-117	118	-200	-277	-123
10.....	284	213	292	51	42	60	-149	-235	-63
11.....	315	226	309	86	57	79	-63	-178	16
12.....	284	241	316	58	75	88	5	-103	104
13.....	258	242	275	36	78	49	31	-25	153
14.....	264	207	160	35	46	-64	66	21	89
15.....	232	55	49	-16	-103	-173	82	-82	-84
16.....	166	23	52	-57	-133	-187	25	-215	-251
17.....	32	36	48	-178	-117	-169	-153	-332	-420
18.....	127	30	320	-80	-121	105	-233	-453	-315
19.....	192	45	301	-12	-103	88	-245	-556	-227
20.....	115	53	58	-86	-93	-153	-331	-649	-380
Decade departure.....							-182	-414	-317
21.....	86	39	46	-112	-104	-163	-443	-753	-543
22.....	131	180	91	-64	39	-116	-507	-714	-669
23.....	191	212	131	-1	73	-74	-508	-641	-733
24.....	165	220	252	-25	83	49	-533	-558	-684
25.....	208	202	256	21	67	55	-612	-491	-629
26.....	230	197	277	46	63	78	-466	-428	-551
27.....	235	199	88	53	66	-109	-413	-362	-660
28.....	36	11	291	-144	-121	96	-557	-483	-564
29.....	234	199	275	57	68	82	-500	-415	-482
30.....	238	190	258	63	60	67	-437	-355	-415
Decade departure.....							-106	+294	-35
Excess or deficiency since first of year.....	gr-cal. -3211			gr-cal. -3211			gr-cal. -3211		
	per cent. -2.6			per cent. -2.6			per cent. -2.6		

## SOME CHARACTERISTICS OF THE MARVIN PYRHELIO-METER.

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[Abstract.]

This pyrheliometer is dynamic in type, in that it is necessary to consider the rate at which the receiver gains heat when exposed to radiation and the rate at which the receiver loses heat when shaded from radiation.

The essential feature of the instrument is the receiver. In the form used in the present work it consisted of a silver disk about 4.5 cm. in diameter and 0.3 cm. thick, in an annular space inside of which is carefully mounted with the best possible thermal contact a noninductive spirally wound coil of No. 35 silk insulated nickel wire

in the form of a 3-lead resistance thermometer, having a total resistance of from 20 to 25 ohms. The coil serves both as the thermometer and as the heater for the purpose of an electrical calibration, the rise in temperature of the thermometer being observed when a known amount of electrical energy is dissipated in the coil. The receiver is mounted within a metal shell, which is incased by a wooden shell in order to reduce local temperature variations to a minimum, and the type of suspension of the receiver is such that thermal losses by conduction are negligible. Before the front face of the receiver a limiting diaphragm is placed, and leading from this, through a hole in the metal and wooden shells, is a diaphragmed and blackened tube which serves the purpose of limiting the cone of rays to a convenient solid angle greater than that subtended by the sun. The end of the tube carries a double-walled aluminum shutter, operated by a magnetic release controlled by a chronograph, which may be so set as to open or close the shutter at any desired instant. For solar work the instrument is mounted as an equatorial telescope and is driven by clockwork, so that the surface of the receiver is always presented normally to the sun.

The determination of the relation between the temperature of the thermometer and its resistance requires an independent experiment in which the receiver is removed from the pyrheliometer and mounted in a constant temperature bath, the temperature of which may be varied over the range required. The temperature relation so found may be accurately expressed by a parabolic equation, and for silver block No. III, which was employed in the present investigation,  $R = 19.521 + 0.08394t + 0.00010127t^2$ , where  $t$  is the temperature centigrade. These data were obtained by Prof. H. H. Kimball, of the United States Weather Bureau.

The electrical calibration was made by subjecting the nickel coil of the thermometer to a measured current and observing the change in temperature indicated by the thermometer. The radiometric calibration was made in a similar manner except that the heat was supplied by radiation from an outside source. The source employed was a Lummer-Kurlbaum black body, or a black body of similar type, electrically heated, with a compensating winding to reduce the temperature gradient and to approximate temperature uniformity. The temperature of the inner inclosure, from which the radiation was taken, was measured by standard platinum, platinum-rhodium thermocouples, accurately calibrated in terms of the melting points of zinc (419.4°), antimony (630.5°), and copper (1083°). A water-cooled diaphragm was mounted directly in front of the opening to the furnace. This diaphragm acts as the effective source of radiation. The equation of rate of energy transfer from the furnace to the pyrheliometer receiver is as follows when  $R$  is large compared with  $\sqrt{A_1}$  and  $\sqrt{A_2}$ .

$$J = \frac{\sigma}{\pi} (T^4 - T_0^4) \frac{A_1 A_2}{R^2}$$

where  $J$  = energy transferred per unit time from furnace to receiver.

$A_1$  = area of water cooled diaphragm in front of furnace.

$A_2$  = area of inmost or effective diaphragm in the pyrheliometer.

$T$  = absolute temperature of furnace.

$T_0$  = absolute temperature of pyrheliometer receiver and surroundings.

$\sigma$  = the Stefan-Boltzmann coefficient of radiation.

$R$  = distance from  $A_1$  to  $A_2$ .

The quantity  $T_0^4$  is negligible, for the present work, in comparison with  $T^4$ .

In the case of electrical calibration,

$$J = i^2 r,$$

where  $i$  is the amperage of the heating current, and  $r$  is the resistance of the thermometer.

The object of the calibration of the pyrheliometer is to evaluate

$$F' = \frac{\Delta J}{\Delta T}$$

where  $\Delta J$  is the heat applied to the pyrheliometric receiver per minute per unit of surface area, and  $\Delta T$  is the measured change in temperature of the coils of the receiver per minute.

Having determined  $F'$ , for solar radiation measurements we have the equation  $\Delta J = F \Delta T$ . ( $F = F' + \text{Cor.}$ )

On account of the lag effect the observed value of  $\Delta T / \Delta t$  ( $t = \text{time}$ ) in the interval 0 to 10 seconds after opening or closing the shutter was found to be too small in the case of radiometric heating and too large in the case of electrical heating. It was therefore omitted from the results, and to reduce temperature changes measured in 50-second intervals to 60-second intervals the factor 1.217 was found necessary. This factor is the same for radiometric as for electrical heating, and its value agrees with that previously determined by the Weather Bureau for electrical heating.

The following table summarizes the results of various experiments with Marvin silver block No. 3. Each experiment represents a series of observations which in most cases extended over an hour. The first column gives the total energy supplied to the disk during each minute of heating. It is clearly shown that the calibration constant  $F'$ , determined electrically, is independent of the amount of energy supplied although this latter extended over a considerable range.

TABLE 1.—Final calibration of Marvin silver block No. 3.  
ELECTRICAL CALIBRATION.

Cal./minute.	$F'$	Cal./minute.	$F'$
0.2704	2.104	0.2755	2.141
0.2713	2.176	0.4925	2.116
0.4871	2.089	0.4945	2.099
0.7859	2.098	0.7772	2.089
0.7997	2.100		
3.138	2.100		2.111
7.211	2.098		
13.181	2.115		
21.321	2.101		
	2.109		
	2.110		

<sup>1</sup> Data taken in November, 1915. <sup>2</sup> Supposedly more accurate data taken March, 1916.

RADIOMETRIC CALIBRATION.

Cal./minute.	$F'$	Temperature of furnace.	Distance between limiting diaphragms
0.1963	2.200	Degrees abs.	Cm.
0.3351	2.173	1,601	94.0
0.4931	2.196	1,602	72.4
0.3138	2.214	1,731	71.9
	2.200	1,649	79.2

A previous electrical calibration by the Weather Bureau gave for  $F'$  the value 2.1308.

The author then applies certain obviously necessary corrections to these results, the most important being a correction of +1.2 per cent to the electrically determined factor on account of incomplete absorption of radiation by the blackened surface of the receiver, and obtains for his mean values

$F = 2.135$  (electrical calibration).

$F = 2.200$  (radiometric calibration).

He gives reasons for considering the radiometric method the more accurate of the two, and then employs the factor  $F = 2.200$  to reduce measurements of solar radiation with Marvin silver block No. 3, made synchronously with measurements by Smithsonian silver block pyrheliometer No. 1. This last instrument was standardized through the Smithsonian Absolute pyrheliometer.

The results are given in Table 2.

TABLE 2.—Data on solar observations.

Date.	Marvin pyrheliometer.	Smithsonian pyrheliometer.	Marvin/Smithsonian.
	Cal./cm <sup>2</sup> min.	Cal./cm <sup>2</sup> min.	
Nov. 10, 1915	1.162	1.189	0.978
Do.	1.352	1.388	.974
Do.	1.262	1.302	.971
Nov. 26, 1915	1.160	1.169	.991
Nov. 27, 1915	1.230	1.253	.980
Mean			.98

The difference, 2 per cent, is considered to be within the probable error of  $F$ , and the results may be considered confirmatory of the accuracy of the Smithsonian standard.

The presentation of the theory of the pyrheliometer while based on recognized fundamental equations, has led to original forms of heating and cooling equations especially adapted to the case under consideration.

#### SUMMARY.

For the first time, it is believed, a pyrheliometer has been calibrated by two methods, the usual electrical method and a radiometric method. In the radiometric method a known quantity of radiation from a black body was allowed to fall upon the pyrheliometer receiver in exactly the same manner as when employed for solar measurements. The calibrations by the two methods agreed within limits of experimental error, if the Stefan-Boltzmann constant were chosen as  $\sigma = 5.7 \times 10^{-12}$  watts cm.<sup>-2</sup> deg.<sup>-4</sup>, the latest and most accurate determination of this constant of total radiation. Or conversely, the constant has been observed as  $5.7 \times 10^{-12}$  within an accuracy of possibly 5 per cent.

The behavior of the Marvin pyrheliometer has been carefully investigated. A lag, part of which is due to the galvanometer of the bridge, has been found to exist, and, for the silver disk No. 3, was experimentally shown to be less than 2 seconds. Both theoretically and experimentally it was shown that the effect of this lag is negligible after 5 to 10 seconds. The cooling and heating of the receiver follows Newton's law of cooling.

In order to completely eliminate errors due to a lag effect, readings should be made at 10 seconds and 60 seconds following the beginning of a heating or cooling. The factor for converting readings of temperature or resistance change over this 50-second interval to corresponding changes over a complete 60-second period is 1.217. This factor is the same for both electrical and radiometric heating and was determined with an accuracy of 0.1 per cent. There is no advantage in making the periods of heating and cooling 120 seconds in duration. Periods of 60 seconds are sufficient. The method of blackening the receiver is of great importance. The best method used for blackening is that used by Coblentz. The calibration constant  $F$  appears independent of the rate at which energy is supplied to the receiver, at least for an electrical calibration.—H. H. K.

## Halo phenomena observed during November, 1918.

[By Willis Ray Gregg, Meteorologist.]

Station.	Altitude.	Latitude.	Longitude.	Date.	Form observed.	Time of—		Theodolite readings.					
						Beginning.	Ending.	Time.	Radius inside.	Radius outside.	Length of arc.	Distance from sun or moon.	Altitude of sun or moon.
Broken Arrow, Okla.*	m. 233	36 02	95 49	None.									
Canton, N. Y.	137	44 36	75 10	None.									
Cincinnati, Ohio.	191	39 06	84 30	7	Solar halo, 22°	9:30 a. m.	12:30 p. m.						
				7	Parhelion, 22° right	11:20 a. m.	11:50 a. m.						
				7	Parhelion, 22° left	11:20 a. m.	11:50 a. m.						
				7	Upper tangent arc	11:20 a. m.	12:30 p. m.						
				24	Lunar halo, 22°	5:25 a. m.	5:45 a. m.						
				24	Solar halo, 22°	12:15 p. m.	12:25 p. m.						
Dayton, Ohio.	274	39 46	84 10	7	Solar halo, 22°	11:00 a. m.	12:30 p. m.						
				11	Solar halo, 22°	8:21 a. m.	10:00 a. m.						
				18	Lunar halo, 22°	6:05 p. m.	7:08 p. m.						
				25	Solar halo, 22°	8:30 a. m.	8:50 a. m.						
Drexel, Nebr.*	306	41 20	96 16	2	Solar halo, 22°	12:00 m.	12:40 p. m.	12:22 p. m.	22	23	270		34
				10	Solar halo, 22°	10:30 a. m.	11:00 a. m.	10:50 a. m.	22	23	160		28
				11	Lunar halo, 22°	6:25 p. m.	10:41 p. m.	6:55 p. m.	22	23	360		28
				12	Solar halo, 22°	8:30 a. m.	9:10 a. m.	9:05 a. m.	22	23	120		16
				14	Lunar halo, 22°	6:55 p. m.	8:35 p. m.						
Ellendale, N. Dak.*	444	45 59	98 34	20	Solar halo, 22°	8:30 a. m.	8:48 a. m.	8:44 a. m.	22	24	360		20
Groesbeck, Tex.*	141	31 30	96 28	29	Parhelion, 22° right	7:54 a. m.	8:00 a. m.	7:56 a. m.			2	22	8.5
				15	Solar halo, 22°	11:40 a. m.	4:00 p. m.	3:50 p. m.			180		
Leesburg, Ga.*	85	31 47	84 14	15	Upper tangent arc	3:35 p. m.	4:00 p. m.	3:50 p. m.			10		
				15	Lunar halo, 22°	5:20 p. m.	D. N.				360		
				20	Solar halo, 22°	1:00 p. m.	2:18 p. m.				360		
				21	Solar halo, 22°	1:37 p. m.	3:15 p. m.	2:15 p. m.			160		
Madison, Wis.	297	43 05	89 23	5	Solar halo, 22°	11:00 a. m.							
				7	Solar halo, 22°	7:20 a. m.	7:40 a. m.						
				10	Solar halo, 22°	11:00 a. m.	11:50 a. m.						
				14	Lunar halo, 22°	7:45 p. m.	9:00 p. m.						
Nashville, Tenn.	166	36 10	86 47	7	Solar halo, 22°	11:30 a. m.	2:00 p. m.						
				14	Lunar halo, 22°	6:00 p. m.	8:00 p. m.						
Royal Center, Ind.*	225	40 53	80 29	12	Solar halo, 22°	11:30 a. m.	12:25 p. m.	12:10 p. m.			360	23.8	31
				14	Lunar halo, 22°	7:30 p. m.	D. N.				360		
				15	Solar halo, 22°	7:45 a. m.	8:05 a. m.	7:50 a. m.			180		11
				16	Lunar halo, 22°	6:25 p. m.	6:45 p. m.				360		

Station.	Date.	Colors.†	Degree of brightness.	Clouds.			Station pressure.	Precipitation.	
				Amount.	Kind.	Direction.		Last previous ended.	First subsequent began.
Broken Arrow, Okla.*	None.								
Canton, N. Y.	None.								
Cincinnati, Ohio.	7	{ R. O. Y. G. B. V. }	Bright.	10	Cl. St.	nw.	Stationary.	2:00 a. m., 1st.	10:55 a. m., 8th.
	7	Dim.							
	7	Dim.							
	7	Dim.							
	24	Dim.		10	A. St.	w.	Stationary.	3:20 p. m., 20th.	1:30 a. m., 28th.
	24	Dim.		8	A. St.	w.	Falling.		
Dayton, Ohio.	7	Dim.		8	Cl. St.	sw.	Falling.	3:50 p. m., 31st.	11:53 a. m., 8th.
	11	Dim.		7	Cl. St.	nw.	Stationary.	7:55 a. m., 9th.	6:05 a. m., 16th.
	16	Dim.		10	Cl. St.	sw.	Falling.	1:05 p. m., 16th.	9:10 p. m., 16th.
	25	Dim.		5	Cl. St.	Rising.	5:20 p. m., 20th.	D. N. a., 24th.	
Drexel, Nebr.*	2	{ R. O. G. G. B. V. }	Brilliant.	6	Cl. St.	w.	Falling.	D. N. p., 30th.	5:00 a. m., 6th.
	10	R.	Dim.	7	Cl. St.	w.	Stationary.	5:00 p. m., 7th.	4:15 p. m., 14th.
	11	Dim.		4	Cl. St.	w.	Rising.	5:00 p. m., 7th.	4:15 p. m., 14th.
	12	{ R. O. Y. G. B. }	Dim.	2	Cl. St.	wnw.	Rising.	5:00 p. m., 7th.	4:15 p. m., 14th.
Ellendale, N. Dak.*	14	Brilliant.		6	Cl. St.	w.	Stationary.	D. N. p., 8th.	9:10 a. m., 15th.
	20	Dim.		8	Cl. St.	w.	Stationary.	11:10 a. m., 15th.	12:40 p. m., 20th.
Groesbeck, Tex.*	29	{ R. O. Y. G. B. I. V. }	Brilliant.	2	A. St.	ssw.	Rising.	7:15 p. m., 27th.	9:05 a. m., 16th.
Leesburg, Ga.*	15	R.	Dim.	8	Cl.	w.	Falling.	5:04 p. m., 30th.	
	15	Bright.		10	A. St.	w.	Falling.		
	20	Dim.		7	Cl. St.	sw.	Stationary.	2:15 p. m., 17th.	2:00 a. m., 22d.
	21	Dim.		8	Cl. St.	ws	Stationary.	2:15 p. m., 17th.	2:00 a. m., 22d.
	5	Dim.		8	Cl. St.	w.	Stationary.	7:10 a. m., 3d.	10:35 a. m., 7th.
	5	Dim.		2	Cl. St.	w.			
Madison, Wis.	7	R.	Dim.	8	A. Cl.	sw.	Stationary.	7:10 a. m., 3d.	10:35 a. m., 7th.
	10	R.	Bright.	8	Cl. St.	w.	Stationary.	12:30 p. m., 9th.	8:27 a. m., 15th.
	14	Bright.		10	Cl. St.	w.	Stationary.	12:30 p. m., 9th.	8:27 a. m., 15th.
Nashville, Tenn.	7	R.	Dim.	9	Cl. St.	nw.	Falling.	4:00 p. m., 31st.	1:00 a. m., 9th.
	14	Dim.		4	A. St.	sw.	Stationary.	10:50 a. m., 9th.	D. N. a., 16th.
	14	Dim.		7	Cl. St.	w.	Falling.	D. N. a., 9th.	D. N. a., 16th.
	14	Bright.		7	Cl. St.	w.	Rising.	D. N. a., 9th.	D. N. a., 16th.
Royal Center, Ind.*	15	R.	Dim.	6	Cl. St.	sw.			D. N. a., 16th.
	15	R.	Dim.	4	A. St.	sw.	Rising.	D. N. a., 9th.	D. N. a., 16th.
	16	R.	Dim.	5	Cl. St.	w.			D. N. a., 17th.
	16	R.	Dim.	3	A. Cu.	s.	Falling.	2:00 p. m., 16th.	

\* Aerological station.

† Beginning with part nearest sun or moon. R. red; O. orange; etc.